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IDENTIFICATION AND CHARACTERIZATION OF SEISMIC SOURCES AND DETERMINATION OF SAFE SHUTDOWN EARTHQUAKE GROUND MOTION

A. INTRODUCTION

In 10 CFR Part 100, "Reactor Site Criteria," Section 100.23, "Geologic and Seismic Siting Factors," paragraph (c), "Geological, Seismological, and Engineering Characteristics," requires that the geological, seismological, and engineering characteristics of a site and its environs be investigated in sufficient scope and detail to permit an adequate evaluation of the proposed site, to provide sufficient information to support evaluations performed to arrive at estimates of the Safe Shutdown Earthquake Ground Motion (SSE), and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. Data on the vibratory ground motion, tectonic surface deformation, nontectonic deformation, earthquake recurrence rates, fault geometry and slip rates, site foundation material, and seismically induced floods, water waves, and other siting factors will be obtained by reviewing pertinent literature and carrying out field investigations.

In 10 CFR 100.23, paragraph (d), "Geologic and Seismic Siting Factors," requires that the geologic and seismic siting factors considered for design include a determination of the SSE for the site, the potential for surface tectonic and nontectonic deformations, the design bases for seismically induced floods and water waves, and other design conditions.

In 10 CFR 100.23, paragraph (d)(1), "Determination of the Safe Shutdown Earthquake Ground Motion," requires that uncertainty inherent in estimates of the SSE be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis or suitable sensitivity analyses.

This guide has been developed to provide general guidance on procedures acceptable to the NRC staff for (1) conducting geological, geophysical, seismological, and geotechnical investigations, (2) identifying and characterizing seismic sources, (3) conducting probabilistic seismic hazard analyses, and (4) determining the SSE for satisfying the requirements of 10 CFR 100.23.

This guide contains several appendices that address the objectives stated above. Appendix A contains a list of definitions of pertinent terms. Appendix B describes the procedure used to determine the reference probability for the SSE exceedance level that is acceptable to the staff. Appendix C discusses the development of a seismic hazard information base and the determination of the probabilistic ground motion level and controlling earthquakes. Appendix D discusses site-specific geological, seismological, and

Electric Power Research Institute (EPRI) (Ref. 7) have been reviewed and accepted by the staff. The LLNL and EPRI studies developed data bases and scientific interpretations of available information and determined seismic sources and source characterizations for the CEUS (e.g., earthquake occurrence rates, estimates of maximum magnitude).

In the CEUS, characterization of seismic sources is more problematic than in the active plate-margin region because there is generally no clear association between seismicity and known tectonic structures or near-surface geology. In general, the observed geologic structures were generated in response to tectonic forces that no longer exist and have little or no correlation with current tectonic forces. Therefore, it is important to account for this uncertainty by the use of multiple alternative models.

The identification of seismic sources and reasonable alternatives in the CEUS considers hypotheses presently advocated for the occurrence of earthquakes in the CEUS (for example, the reactivation of favorably oriented zones of weakness or the local amplification and release of stresses concentrated around a geologic structure). In tectonically active areas of the CEUS, such as the New Madrid Seismic Zone, where geological, seismological, and geophysical evidence suggest the nature of the sources that generate the earthquakes, it may be more appropriate to evaluate those seismic sources by using procedures similar to those normally applied in the Western United States.

WESTERN UNITED STATES

The Western United States is considered to be that part of the United States that lies west of the Rocky Mountain front, or west of approximately 105° West Longitude. For the Western United States, an information base of earth science data and scientific interpretations of seismic sources and source characterizations (e.g., geometry, seismicity parameters) comparable to the CEUS as documented in the LLNL and EPRI studies (Refs. 4–7) does not exist. For this region, specific interpretations on a site-by-site basis should be applied (Ref. 1).

The active plate-margin region includes, for example, coastal California, Oregon, Washington, and Alaska. For the active plate-margin region, where earthquakes can often be correlated with known tectonic structures, those structures should be assessed for their earthquake and surface deformation potential. In this region, at least three types of sources exist: (1) faults that are known to be at or near the surface, (2) buried (blind) sources that may often be manifested as folds at the earth's surface, and (3) subduction zone sources, such as those in the Pacific Northwest. The nature of surface faults can be evaluated by conventional surface and near-surface investigation techniques to assess orientation, geometry, sense of displacements, length of rupture, Quaternary history, etc.

Buried (blind) faults are often associated with surficial deformation such as folding, uplift, or subsidence. The surface expression of blind faulting can be detected by mapping the uplifted or down-dropped geomorphological features or stratigraphy, survey leveling, and geodetic methods. The nature of the structure at depth can often be evaluated by core borings and geophysical techniques.

Continental United States subduction zones are located in the Pacific Northwest and Alaska. Seismic sources associated with subduction zones are sources within the overriding plate, on the interface between the subducting and overriding lithospheric plates, and in the interior of the downgoing oceanic slab. The characterization of subduction zone seismic sources includes consideration of the three-dimensional geometry of the subducting plate, rupture segmentation of subduction zones, geometry of historical ruptures, constraints on the up-dip and down-dip extent of rupture, and comparisons with other subduction zones worldwide.

The Basin and Range region of the Western United States, and to a lesser extent the Pacific Northwest and the Central United States, exhibit temporal clustering of earthquakes. Temporal clustering is best exemplified by the rupture histories within the Wasatch fault zone in Utah and the Meers fault in central Oklahoma, where several large late Holocene coseismic faulting events occurred at relatively close intervals (hundreds to thousands of years) that were preceded by long periods of quiescence that lasted thousands to tens of thousand years. Temporal clustering should be considered in these regions or wherever paleoseismic evidence indicates that it has occurred.

C. REGULATORY POSITION

1. GEOLOGICAL, GEOPHYSICAL, SEISMOLOGICAL, AND GEOTECHNICAL INVESTIGATIONS

1.1 Comprehensive geological, seismological, geophysical, and geotechnical investigations of the site and regions around the site should be performed.

their rupture and ground motion generating potential while the excavations' walls and bases are exposed. Therefore, a commitment should be made, in documents (Safety Analysis Reports) supporting the license application, to geologically map all excavations and to notify the NRC staff when excavations are open for inspection.

1.4 Data sufficient to clearly justify all conclusions should be presented. Because engineering solutions cannot always be satisfactorily demonstrated for the effects of permanent ground displacement, it is prudent to avoid a site that has a potential for surface or near-surface deformation. Such sites normally will require extensive additional investigations.

1.5 For the site and for the area surrounding the site, the lithologic, stratigraphic, hydrologic, and structural geologic conditions should be characterized. The investigations should include the measurement of the static and dynamic engineering properties of the materials underlying the site and an evaluation of physical evidence concerning the behavior during prior earthquakes of the surficial materials and the substrata underlying the site. The properties needed to assess the behavior of the underlying material during earthquakes, including the potential for liquefaction, and the characteristics of the underlying material in transmitting earthquake ground motions to the foundations of the plant (such as seismic wave velocities, density, water content, porosity, elastic moduli, and strength) should be measured.

2. SEISMIC SOURCES SIGNIFICANT TO THE SITE SEISMIC HAZARD

2.1 For sites in the CEUS, when the EPRI or LLNL PSHA methodologies and data bases are used to determine the SSE, it still may be necessary to investigate and characterize potential seismic sources that were previously unknown or uncharacterized and to perform sensitivity analyses to assess their significance to the seismic hazard estimate. The results of investigations discussed in Regulatory Position 1 should be used, in accordance with Appendix E, to determine whether the LLNL or EPRI seismic sources and their characterization should be updated. The guidance in Regulatory Positions 2.2 and 2.3 below and in Appendix D of this guide may be used if additional seismic sources are to be developed as a result of investigations.

2.2 When the LLNL and EPRI methods are not used or are not applicable, the guidance in Regulatory Position 2.3 should be used for identification and characterization of seismic sources. The uncertainties in the characterization of seismic sources should be addressed as appropriate. Seismic source is a general term referring to both seismogenic sources and capable tectonic sources. The main distinction between these two types of seismic sources is that a seismogenic source would not cause surface displacement, but a capable tectonic source causes surface or near-surface displacement.

Identification and characterization of seismic sources should be based on regional and site geological and geophysical data, historical and instrumental seismicity data, the regional stress field, and geological evidence of prehistoric earthquakes. Investigations to identify seismic sources are described in Appendix D. The bases for the identification of seismic sources should be documented. A general list of characteristics to be evaluated for a seismic source is presented in Appendix D.

2.3 As part of the seismic source characterization, the seismic potential for each source should be evaluated. Typically, characterization of the seismic potential consists of four equally important elements:

1. Selection of a model for the spatial distribution of earthquakes in a source.
2. Selection of a model for the temporal distribution of earthquakes in a source.
3. Selection of a model for the relative frequency of earthquakes of various magnitudes, including an estimate for the largest earthquake that could occur in the source under the current tectonic regime.
4. A complete description of the uncertainty.

For example, in the LLNL study a truncated exponential model was used for the distribution of magnitudes given that an earthquake has occurred in a source. A stationary Poisson process is used to model the spatial and temporal occurrences of earthquakes in a source.

For a general discussion of evaluating the earthquake potential and characterizing the uncertainty, refer to the Senior Seismic Hazard Analysis Committee Report (Ref. 9).

2.3.1 For sites in the CEUS, when the LLNL or EPRI method is not used or not applicable (such as in the New Madrid Seismic Zone), it is necessary to evaluate the seismic potential for each source. The seismic sources and data that have been accepted by the NRC in past licensing decisions may be used, along with the details of the calculational aspects of deriving controlling earthquakes from the PSHA are included in Appendix C.

1. Perform regional and site geological, seismological, and geophysical investigations in accordance with Regulatory Position 1 and Appendix D.

2. For CEUS sites, perform an evaluation of LLNL or EPRI seismic sources in accordance with Appendix E to determine whether they are consistent with the site-specific data gathered in Step 1 or require updating. The PSHA should only be updated if the new information indicates that the current version significantly underestimates the hazard and there is a strong technical basis that supports such a revision. It may be possible to justify a lower hazard estimate with an exceptionally strong technical basis. However, it is expected that large uncertainties in estimating seismic hazard in the CEUS will continue to exist in the future, and substantial delays in the licensing process will result in trying to justify a lower value with respect to a specific site. For these reasons the NRC staff discourages efforts to justify a lower hazard estimate. In most cases, limited-scope sensitivity studies should be sufficient to demonstrate that the existing data base in the PSHA envelops the findings from site-specific investigations. In general, significant revisions to the LLNL and EPRI data base are to be undertaken only periodically (every 10 years), or when there is an important new finding or occurrence. An overall revision of the data base would also require a reexamination of the acceptability of the reference probability discussed in Appendix B and used in Step 4 below. Any significant update should follow the guidance of Reference 9.

3. For CEUS sites only, perform the LLNL or EPRI probabilistic seismic hazard analysis using original or updated sources as determined in Step 2. For sites in other parts of the country, perform a site-specific PSHA (Reference 9). The ground motion estimates should be made for rock conditions in the free-field or by assuming hypothetical rock conditions for a nonrock site to develop the seismic hazard information base discussed in Appendix C.

4. Using the reference probability (1E-5 per year) described in Appendix B, determine the 5% of critically damped median spectral ground motion levels for the average of 5 and 10 Hz, $S_{a,5\text{-}10}$, and for the average of 1 and 2.5 Hz, $S_{a,1\text{-}2.5}$. Appendix B discusses situations in which an alternative reference probability may be more appropriate. The alternative reference probability is reviewed and accepted on a case-by-case basis. Appendix B also describes a procedure that should be used when a general revision to the reference probability is needed.

5. Deaggregate the median probabilistic hazard characterization in accordance with Appendix C to determine the controlling earthquakes (i.e., magnitudes and distances). Document the hazard information base as discussed in Appendix C.

4. PROCEDURES FOR DETERMINING THE SSE

After completing the PSHA (See Regulatory Position 3) and determining the controlling earthquakes, the following procedure should be used to determine the SSE. Appendix F contains an additional discussion of some of the characteristics of the SSE.

1. With the controlling earthquakes determined as described in Regulatory Position 3 and by using the procedures in Revision 3 of Standard Review Plan (SRP) Section 2.5.2 (which may include the use of ground motion models not included in the PSHA but that are more appropriate for the source, region, and site under consideration or that represent the latest scientific development), develop 5% of critical damping response spectral shapes for the actual or assumed rock conditions. The same controlling earthquakes are also used to derive vertical response spectral shapes.

2. Use $S_{a,5\text{-}10}$ to scale the response spectrum shape corresponding to the controlling earthquake. If, as described in Appendix C, there is a controlling earthquake for $S_{a,1\text{-}2.5}$, determine that the $S_{a,5\text{-}10}$ scaled response spectrum also envelopes the ground motion spectrum for the controlling earthquake for $S_{a,1\text{-}2.5}$. Otherwise, modify the shape to envelope the low-frequency spectrum or use two spectra in the following steps. See additional discussion in Appendix F. For a rock site go to Step 4.

3. For nonrock sites, perform a site-specific soil amplification analysis considering uncertainties in site-specific geotechnical properties and parame-

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[1] Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

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Seismogenic Source — A seismogenic source is a portion of the earth that we assume has uniform earthquake potential (same expected maximum earthquake and recurrence frequency), distinct from the seismicity of the surrounding regions. A seismogenic source will generate vibratory ground motion but is assumed not to cause surface displacement. Seismogenic sources cover a wide range of possibilities from a well-defined tectonic structure to simply a large region of diffuse seismicity (seismotectonic province) thought to be characterized by the same earthquake recurrence model. A seismogenic source is also characterized by its involvement in the current tectonic regime (the Quaternary, or approximately the last 2 million years).

Stable Continental Region — A stable continental region (SCR) is composed of continental crust, including continental shelves, slopes, and attenuated continental crust, and excludes active plate boundaries and zones of currently active tectonics directly influenced by plate margin processes. It exhibits no significant deformation associated with the major Mesozoic-to-Cenozoic (last 240 million years) orogenic belts. It excludes major zones of Neogene (last 25 million years) rifting, volcanism, or suturing.

Stationary Poisson Process — A probabilistic model of the occurrence of an event over time (space) that is characterized by (1) the occurrence of the event in small intervals is constant over time (space), (2) the occurrence of two (or more) events in a small interval is negligible, and (3) the occurrence of the event in non-overlapping intervals is independent.

Tectonic Structure — A tectonic structure is a large-scale dislocation or distortion, usually within the earth's crust. Its extent may be on the order of tens of meters (yards) to hundreds of kilometers (miles).

Table B.1
Plants/Sites Used in Determining Reference Probability

Plant/Site Name	Soil Condition Primary/Secondary*	Plant/Site Name	Soil Condition Primary/Secondary*
Limerick	Rock	Byron	Rock
Shearon Harris	Sand – S1	Clinton	Till – T3
Braidwood	Rock	Davis Besse	Rock
River Bend	Deep Soil	LaSalle	Till – T2
Wolf Creek	Rock	Perry	Rock
Watts Bar	Rock	Bellefonte	Rock
Vogtle	Deep Soil	Callaway	Rock/Sand – S1
Seabrook	Rock	Comanche Peak	Rock
Three Mile Is.	Rock/Sand – S1	Grand Gulf	Deep Soil
Catawba	Rock/Sand – S1	South Texas	Deep Soil
Hope Creek	Deep Soil	Waterford	Deep Soil
McGuire	Rock	Millstone 3	Rock
North Anna	Rock/Sand – S1	Nine Mile Point	Rock/Sand – S1
Summer	Rock/Sand – S1	Brunswick	Sand – S1
Beaver Valley	Sand – S1		

*If two soil conditions are listed, the first is the primary and the second is the secondary soil condition. See Ref. B.1 for a discussion of soil conditions.

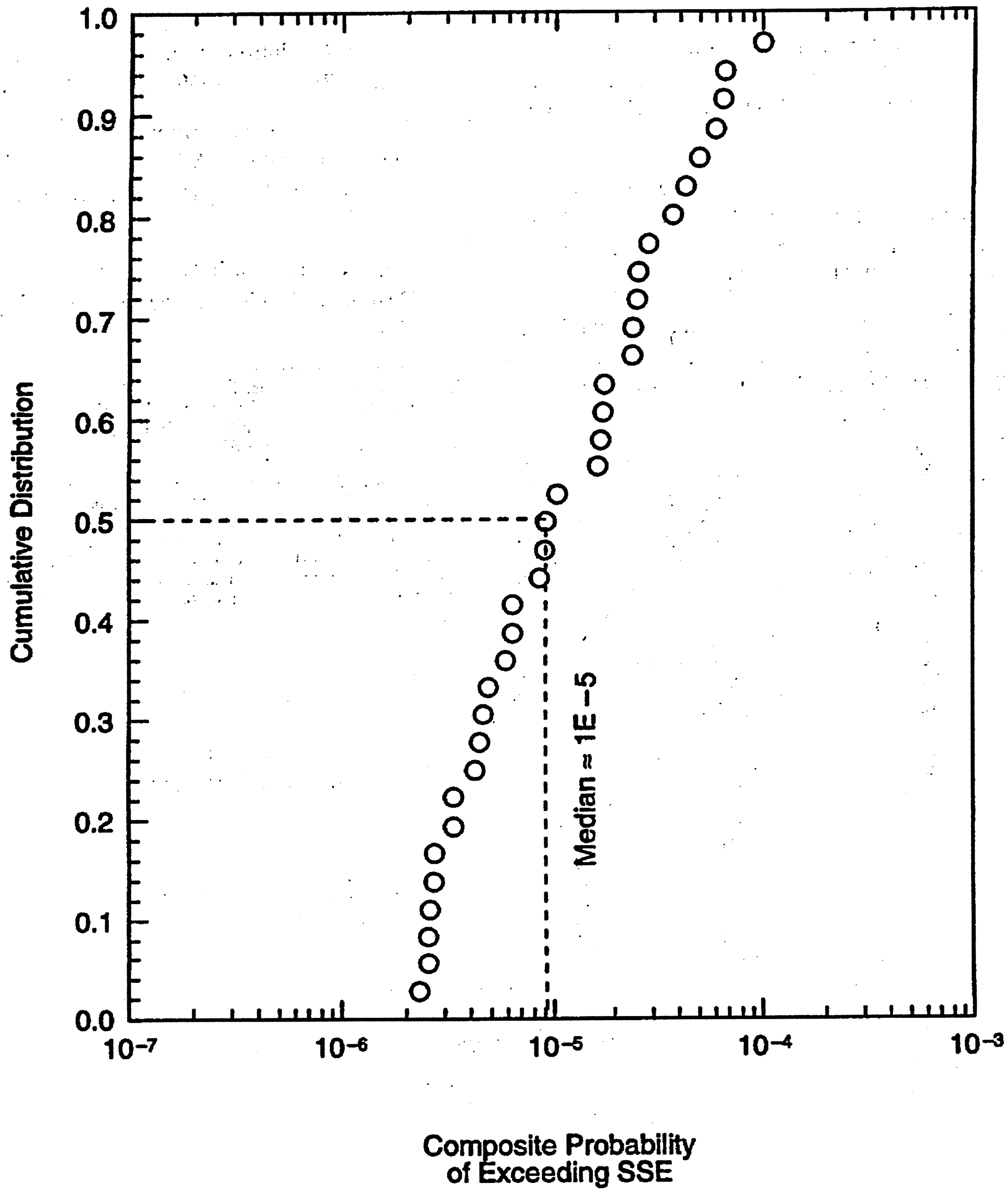

Figure B.2 Probability of Exceeding SSE
Using Median LLNL Hazard Estimates

APPENDIX C
DETERMINATION OF CONTROLLING EARTHQUAKES AND DEVELOPMENT OF SEISMIC HAZARD INFORMATION BASE

C.1 INTRODUCTION

This appendix elaborates on the steps described in Regulatory Position 3 of this regulatory guide to determine the controlling earthquakes used to define the Safe Shutdown Earthquake Ground Motion (SSE) at the site and to develop a seismic hazard information base. The information base summarizes the contribution of individual magnitude and distance ranges to the seismic hazard and the magnitude and distance values of the controlling earthquakes at the average of 1 and 2.5 Hz and the average of 5 and 10 Hz. They are developed for the ground motion level corresponding to the reference probability as defined in Appendix B to this regulatory guide.

The spectral ground motion levels, as determined from a probabilistic seismic hazard analysis (PSHA), are used to scale a response spectrum shape. A site-specific response spectrum shape is determined for the controlling earthquakes and local site conditions. Regulatory Position 4 and Appendix F to this regulatory guide describe a procedure to determine the SSE using the controlling earthquakes and results from the PSHA.

C.2 PROCEDURE TO DETERMINE CONTROLLING EARTHQUAKES

The following is an approach acceptable to the NRC staff for determining the controlling earthquakes and developing a seismic hazard information base. This procedure is based on a de-aggregation of the probabilistic seismic hazard in terms of earthquake magnitudes and distances. Once the controlling earthquakes have been obtained, the SSE response spectrum can be determined according to the procedure described in Appendix F to this regulatory guide.

Step 1

Perform a site-specific PSHA using the Lawrence Livermore National Laboratory (LLNL) or Electric Power Research Institute (EPRI) methodologies for Central and Eastern United States (CEUS) sites or perform a site-specific PSHA for sites not in the CEUS or for sites for which LLNL or EPRI methods and data are not applicable, for actual or assumed rock conditions. The hazard assessment (mean, median, 85th percentile, and 15th percentile) should be performed for spectral accelerations at 1, 2.5, 5, 10, and 25 Hz, and the peak ground acceleration. A lower-bound magnitude of 5.0 is recommended.

Step 2

(a) Using the reference probability (1E–5/yr) as defined in Appendix B to this regulatory guide, determine the ground motion levels for the spectral accelerations at 1, 2.5, 5, and 10 Hz from the total *median* hazard obtained in Step 1.

(b) Calculate the average of the ground motion level for the 1 and 2.5 Hz and the 5 and 10 Hz spectral acceleration pairs.

Step 3

Perform a complete probabilistic seismic hazard analysis for each of the magnitude-distance bins illustrated in Table C.1. (These magnitude-distance bins are to be used in conjunction with the LLNL or EPRI methods. For other situations, other binning schemes may be necessary.)

Table C.1
Recommended Magnitude and Distance Bins

	Magnitude Range of Bin				
Distance Range of Bin (km)	5 – 5.5	5.5 – 6	6 – 6.5	6.5 – 7	>7
0 – 15					
15 – 25					
25 – 50					
50 – 100					
100 – 200					
200 – 300					
> 300					

$$Ln\ \{D_c\,(1-2.5\,Hz)\} \;=\; \sum_{d>100} Ln(d) \sum_{m} P > 100(m,d)_2$$

Equation (7)

where d is the centroid distance value for each distance bin.

Step 8

Determine the SSE response spectrum using the procedure described in Appendix F of this regulatory guide.

C.3 EXAMPLE FOR A CEUS SITE

To illustrate the procedure in Section C.2, calculations are shown here for a CEUS site using the 1993 LLNL hazard results (Refs. C.1 and C.2). It must be emphasized that the recommended magnitude and distance bins and procedure used to establish controlling earthquakes were developed for application in the CEUS where the nearby earthquakes generally control the response in the 5 to 10 Hz frequency range, and larger but distant events can control the lower frequency range. For other situations, alternative binning schemes as well as a study of contributions from various bins will be necessary to identify controlling earthquakes consistent with the distribution of the seismicity.

Step 1

The 1993 LLNL seismic hazard methodology (Refs. C.1 and C.2) was used to determine the hazard at the site. A lower bound magnitude of 5.0 was used in this analysis. The analysis was performed for spectral acceleration at 1, 2.5, 5, and 10 Hz. The resultant hazard curves are plotted in Figure C.1.

Step 2

The hazard curves at 1, 2.5, 5, and 10 Hz obtained in Step 1 are assessed at the reference probability value of 1E–5/yr, as defined in Appendix B to this regulatory guide. The corresponding ground motion level values are given in Table C.2. See Figure C.1.

The average of the ground motion levels at the 1 and 2.5 Hz, $S_{a1\text{-}2.5}$, and 5 and 10 Hz, $S_{a5\text{-}10}$, are given in Table C.3.

Step 3

The median seismic hazard is de-aggregated for the matrix of magnitude and distance bins as given in Table C.1.

A complete probabilistic hazard analysis was performed for each bin to determine the contribution to the hazard from all earthquakes within the bin, e.g., all earthquakes with magnitudes 6 to 6.5 and distance 25 to 50 km from the site. See Figure C.2 where the median 1 Hz hazard curve is plotted for distance bin 25 – 50 km and magnitude bin 6 – 6.5.

The hazard values corresponding to the ground motion levels found in step 2, and listed in Table C.2, are then determined from the hazard curve for each bin for spectral accelerations at 1, 2.5, 5, and 10 Hz. This process is illustrated in Figure C.2. The vertical line corresponds to the value 88 cm/s/s listed in Table C.2 for the 1 Hz hazard curve and intersects the hazard curve for the 25 – 50 bin, 6 – 6.5 bin at a hazard value (probability of exceedance) of 2.14E–08 per year. Tables C.4 to C.7 list the appropriate hazard value for each bin for 1, 2.5, 5, and 10 Hz respectively.

It should be noted that if the median hazard in each of the 35 bins is added up it does not equal 1.0E–05. That is because the sum of the median of each of the bins does not equal the overall median. However, if we gave the mean hazard for each bin it would add up to the overall mean hazard curve.

Step 4

Using de-aggregated median hazard results, the fractional contribution of each magnitude-distance pair to the total hazard is determined.

Tables C.8 and C.9 show $P(m,d)_1$ and $P(m,d)_2$ for the average of 1 and 2.5 Hz and 5 and 10 Hz, respectively.

Step 5

Because the contribution of the distance bins greater than 100 km in Table C.8 contains more than 5% of the total hazard for the average of 1 and 2.5 Hz, the controlling earthquake for the spectral average of 1 and 2.5 Hz will be calculated using magnitude-distance bins for distance greater than 100 km. Table C.10 shows $P_{>100}$ (m,d)1 for the average of 1 to 2.5 Hz.

Table C.6
Median Exceeding Probability Values for Spectral Accelerations at 5 Hz (351 cm/s/s)

	Magnitude Range of Bin				
Distance Range of Bin (km)	5 – 5.5	5.5 – 6	6 – 6.5	6.5 – 7	>7
0 – 15	4.96E–07	5.85E–07	5.16E–08	0	0
15 – 25	9.39E–08	2.02E–07	1.36E–08	0	0
25 – 50	2.76E–08	1.84E–07	7.56E–08	0	0
50 – 100	1.23E–08	3.34E–08	9.98E–08	2.85E–08	0
100 – 200	8.06E–12	1.14E–09	2.54E–08	1.55E–07	0
200 – 300	0	2.39E–13	2.72E–11	4.02E–10	0
> 300	0	0	0	0	0

Table C.7
Median Exceeding Probability Values for Spectral Accelerations at 10 Hz (551 cm/s/s)

	Magnitude Range of Bin				
Distance Range of Bin (km)	5 – 5.5	5.5 – 6	6 – 6.5	6.5 – 7	>7
0 – 15	1.11E–06	1.12E–06	8.30E–08	0	0
15 – 25	2.07E–07	3.77E–07	3.12E–08	0	0
25 – 50	4.12E–08	2.35E–07	1.03E–07	0	0
50 – 100	5.92E–10	2.30E–08	6.89E–08	2.71E–08	0
100 – 200	1.26E–12	1.69E–10	6.66E–09	5.43E–08	0
200 – 300	0	3.90E–15	6.16E–13	2.34E–11	0
> 300	0	0	0	0	0

Figures C.3 to C.5 show the above information in terms of the relative percentage contribution.

Steps 6 and 7

To compute the controlling magnitudes and distances at 1 to 2.5 Hz and 5 to 10 Hz for the example site, the values of $P_{>100}(m,d)_1$ and $P(m,d)_2$ are used with m and d values corresponding to the mid-point of the magnitude of the bin (5.25, 5.75, 6.25, 6.75, 7.3) and centroid of the ring area (10, 20.4, 38.9, 77.8, 155.6, 253.3, and somewhat arbitrarily 350 km). Note that the mid-point of the last magnitude bin may change because this value is dependent on the maximum magnitudes used in the hazard analysis. For this example site, the controlling earthquake characteristics (magnitudes and distances) are given in Table C.11.

Step 8

The SSE response spectrum is determined by the procedures described in Appendix F.

C.4 SITES NOT IN THE CEUS

The determination of the controlling earthquakes and the seismic hazard information base for sites not in the CEUS is also carried out using the procedure described in Section C.2 of this appendix. However, because of differences in seismicity rates and ground motion attenuation at these sites, alternative magnitude-distance bins may have to be used. In addition, as discussed in Appendix B, an alternative reference probability may also have to be developed, particularly for sites in the active plate margin region and for sites at which a known tectonic structure dominates the hazard.

Table C.11
Magnitudes and Distances of Controlling Earthquakes from the LLNL Probabilistic Analysis

1 – 2.5 Hz	5 – 10 Hz
M_c and D_c > 100 km	M_c and D_c
6.7 and 157 km	5.7 and 17 km

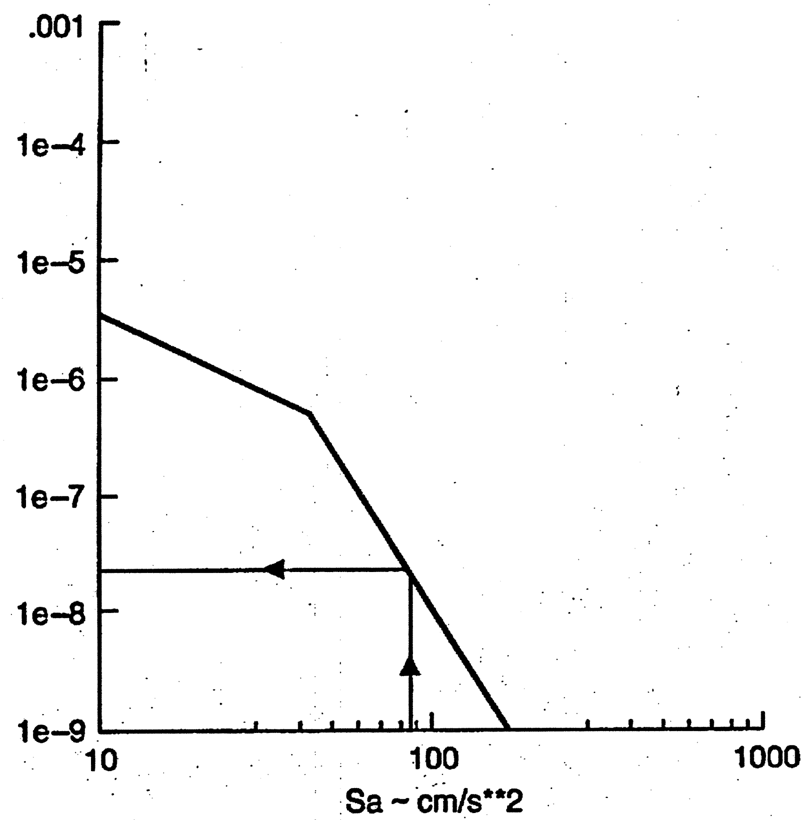

Figure C.2 1 Hz Median Hazard Curve for
Distance Bin 25 – 50 km & Magnitude Bin 6 – 6.5

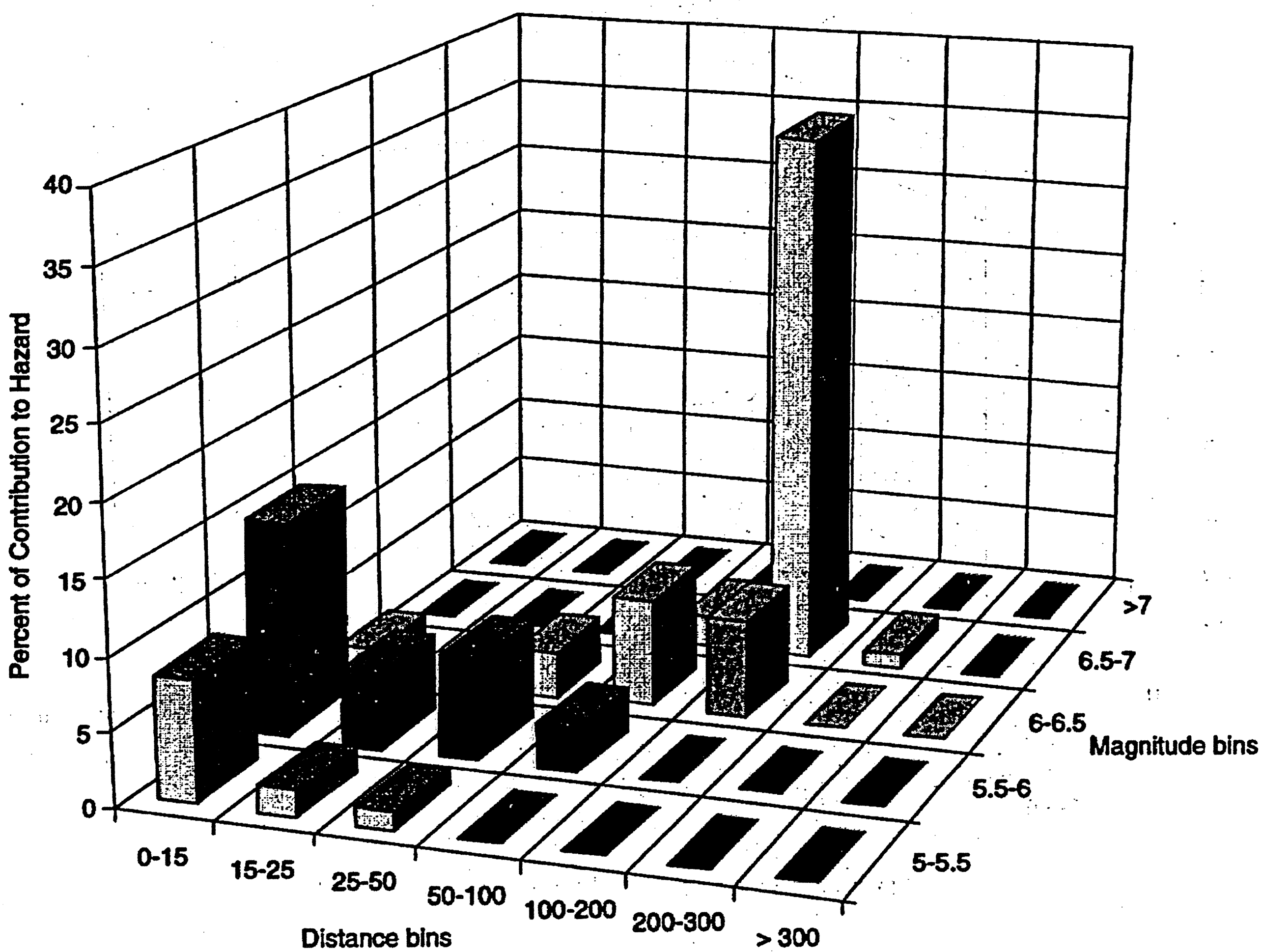

Figure C.4 Full Distribution for Average of 1 and 2.5 Hz

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C.1 P. Sobel, "Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains, NUREG–1488, USNRC, April 1994.[1]

C.2 J.B. Savy et al., "Eastern Seismic Hazard Characterization Update," UCRL–ID–115111, Lawrence Livermore National Laboratory, June 1993 (Accession number 9310190318 in NRC's Public Document Room).[2]

[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

[2]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

respect to faults, and displacement history or uplift rates of seismogenic folds),

- The late Quaternary interaction between faults that compose a fault system and the interaction between fault systems.
- Effects of human activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the construction of dams and reservoirs,
- Volcanism. Volcanic hazard is not addressed in this regulatory guide. It will be considered on a case-by-case basis in regions where a potential for this hazard exists.

D.2. INVESTIGATIONS TO EVALUATE SEISMIC SOURCES

D.2.1 General

Investigations of the site and region around the site are necessary to identify both seismogenic sources and capable tectonic sources and to determine their potential for generating earthquakes and causing surface deformation. If it is determined that surface deformation need not be taken into account at the site, sufficient data to clearly justify the determination should be presented in the application for an early site permit, construction permit, operating license, or combined license. Generally, any tectonic deformation at the earth's surface within 40 km (25 miles) of the site will require detailed examination to determine its significance. Potentially active tectonic deformation within the seismogenic zone beneath a site will have to be assessed using geophysical and seismological methods to determine its significance.

Engineering solutions are generally available to mitigate the potential vibratory effects of earthquakes through design. However, engineering solutions cannot always be demonstrated to be adequate for mitigation of the effects of permanent ground displacement phenomena such as surface faulting or folding, subsidence, or ground collapse. For this reason, it is prudent to select an alternative site when the potential for permanent ground displacement exists at the proposed site (Ref. D.2).

In most of the CEUS, instrumentally located earthquakes seldom bear any relationship to geologic structures exposed at the ground surface. Possible geologically young fault displacements either do not extend to the ground surface or there is insufficient geologic material of the appropriate age available to date the faults. Capable tectonic sources are not always exposed at the ground surface in the Western United States as demonstrated by the buried (blind) reverse causative faults of the 1983 Coalinga, 1988 Whittier Narrows, 1989 Loma Prieta, and 1994 Northridge earthquakes. These factors emphasize the need to conduct thorough investigations not only at the ground surface but also in the subsurface to identify structures at seismogenic depths.

The level of detail for investigations should be governed by knowledge of the current and late Quaternary tectonic regime and the geological complexity of the site and region. The investigations should be based on increasing the amount of detailed information as they proceed from the regional level down to the site area (e.g., 320 km to 8 km distance from the site). Whenever faults or other structures are encountered at a site (including sites in the CEUS) in either outcrop or excavations, it is necessary to perform many of the investigations described below to determine whether or not they are capable tectonic sources.

The investigations for determining seismic sources should be carried out at three levels, with areas described by radii of 320 km (200 mi), 40 km (25 mi), and 8 km (5 mi) from the site. The level of detail increases closer to the site. The specific site, to a distance of at least 1 km (0.6 mi), should be investigated in more detail than the other levels.

The regional investigations [within a radius of 320 km (200 mi) of the site] should be planned to identify seismic sources and describe the Quaternary tectonic regime. The data should be presented at a scale of 1:500,000 or smaller. The investigations are not expected to be extensive or in detail, but should include a comprehensive literature review supplemented by focused geological reconnaissances based on the results of the literature study (including topographic, geologic, aeromagnetic, and gravity maps, and airphotos). Some detailed investigations at specific locations within the region may be necessary if potential capable tectonic sources, or seismogenic sources that may be significant for determining the safe shutdown earthquake ground motion, are identified.

The large size of the area for the regional investigations is recommended because of the possibility that all significant seismic sources, or alternative configurations, may not have been enveloped by the LLNL/EPRI data base. Thus, it will increase the chances of (1) identifying evidence for unknown seismic sources that might extend close enough for earthquake ground motions generated by that source to affect the site and (2) confirming the PSHA's data base. Furthermore, because of the relatively aseismic nature of the CEUS, the area should be large enough to include as many historical and instrumentally recorded earthquakes for every site, and situations will occur that require investigations that are not included in the following discussion. It is anticipated that new technologies will be available in the future that will be applicable to these investigations.

D.2.3.1 Surface Investigations

Surface exploration needed to assess the neotectonic regime and the geology of the area around the site is dependent on the site location and may be carried out with the use of any appropriate combination of the geological, geophysical, seismological, and geotechnical engineering techniques summarized in the following paragraphs and Ref. D.3. However, not all of these methods must be carried out at a given site.

D.2.3.1.1. Geological interpretations of aerial photographs and other remote-sensing imagery, as appropriate for the particular site conditions, to assist in identifying rock outcrops, faults and other tectonic features, fracture traces, geologic contacts, lineaments, soil conditions, and evidence of landslides or soil liquefaction.

D.2.3.1.2. Mapping of topographic, geologic, geomorphic, and hydrologic features at scales and with contour intervals suitable for analysis, stratigraphy (particularly Quaternary), surface tectonic structures such as fault zones, and Quaternary geomorphic features. For offshore sites, coastal sites, or sites located near lakes or rivers, this includes topography, geomorphology (particularly mapping marine and fluvial terraces), bathymetry, geophysics (such as seismic reflection), and hydrographic surveys to the extent needed for evaluation.

D.2.3.1.3. Identification and evaluation of vertical crustal movements by (1) geodetic land surveying to identify and measure short-term crustal movements (Refs. D.4 and D.5) and (2) geological analyses such as analysis of regional dissection and degradation patterns, marine and lacustrine terraces and shorelines, fluvial adjustments such as changes in stream longitudinal profiles or terraces, and other long-term changes such as elevation changes across lava flows (Ref. D.6).

D.2.3.1.4. Analysis of offset, displaced, or anomalous landforms such as displaced stream channels or changes in stream profiles or the upstream migration of knickpoints (Refs. D.7 through D.12); abrupt changes in fluvial deposits or terraces; changes in paleochannels across a fault (Refs. D.11 and D.12); or uplifted, downdropped, or laterally displaced marine terraces (Ref. D.12).

D.2.3.1.5. Analysis of Quaternary sedimentary deposits within or near tectonic zones, such as fault zones, including (1) fault-related or fault-controlled deposits such as sag ponds, graben fill deposits, and colluvial wedges formed by the erosion of a fault paleoscarp and (2) non-fault-related, but offset, deposits such as alluvial fans, debris cones, fluvial terrace, and lake shoreline deposits.

D.2.3.1.6. Identification and analysis of deformation features caused by vibratory ground motions, including seismically induced liquefaction features (sand boils, explosion craters, lateral spreads, settlement, soil flows), mud volcanoes, landslides, rockfalls, deformed lake deposits or soil horizons, shear zones, cracks or fissures (Refs. D.13 and D.14).

D.2.3.1.7. Analysis of fault displacements, such as by the interpretion of the morphology of topographic fault scarps associated with or produced by surface rupture. Fault scarp morphology is useful in estimating the age of last displacement (in conjunction with the appropriate geochronological methods described in Subsection D.2.4, approximate size of the earthquake, recurrence intervals, slip rate, and the nature of the causative fault at depth (Refs. D.15 through D.18).

D.2.3.2 Seismological Investigations

D.2.3.2.1. Listing of all historically reported earthquakes having Modified Mercalli Intensity (MMI) greater than or equal to IV or magnitude greater than or equal to 3.0 that can reasonably be associated with seismic sources, any part of which is within a radius of 320 km (200 miles) of the site (the site region). The earthquake descriptions should include the date of occurrence and measured or estimated data on the highest intensity, magnitude, epicenter, depth, focal mechanism, and stress drop. Historical seismicity includes both historically reported and instrumentally recorded data. For earthquakes without instrumentally recorded data or calculated magnitudes, intensity should be converted to magnitude, the procedure used to convert it to magnitude should be clearly documented, and epicenters should be determined based on intensity distributions. Methods to convert intensity values to magnitudes in the CEUS are described in References D.1 and D.19 through D.21.

D.2.3.2.2. Seismic monitoring in the site area should be established as soon as possible after site selection. For sites in both the CEUS and WUS, a single large dynamic range, broad-band seismograph, and a network of short period instruments to locate events should be deployed around the site area.

In the CEUS, it may not be possible to reasonably demonstrate the age of last activity of a tectonic structure. In such cases the NRC staff will accept association of such structures with geologic structural features or tectonic processes that are geologically old (at least pre-Quaternary) as an age indicator in the absence of conflicting evidence.

These investigative procedures should also be applied, where possible, to characterize offshore structures (faults or fault zones, and folds, uplift, or subsidence related to faulting at depth) for coastal sites or those sites located adjacent to landlocked bodies of water. Investigations of offshore structures will rely heavily on seismicity, geophysics, and bathymetry rather than conventional geologic mapping methods that normally can be used effectively onshore. However, it is often useful to investigate similar features onshore to learn more about the significant offshore features.

D.2.5 Distinction Between Tectonic and Nontectonic Deformation

At a site, both nontectonic deformation and tectonic deformation can pose a substantial hazard to nuclear power plants, but there are likely to be differences in the approaches used to resolve the issues raised by the two types of phenomena. Therefore, nontectonic deformation should be distinguished from tectonic deformation at a site. In past nuclear power plant licensing activities, surface displacements caused by phenomena other than tectonic phenomena have been confused with tectonically induced faulting. Such features include faults on which the last displacement was induced by glaciation or deglaciation; collapse structures, such as found in karst terrain; and growth faulting, such as occurs in the Gulf Coastal Plain or in other deep soil regions subject to extensive subsurface fluid withdrawal.

Glacially induced faults generally do not represent a deep-seated seismic or fault displacement hazard because the conditions that created them are no longer present. However, residual stresses from Pleistocene glaciation may still be present in glaciated regions, although they are of less concern than active tectonically induced stresses. These features should be investigated with respect to their relationship to current in situ stresses.

The nature of faults related to collapse features can usually be defined through geotechnical investigations and can either be avoided or, if feasible, adequate engineering fixes can be provided.

Large, naturally occurring growth faults as found in the coastal plain of Texas and Louisiana can pose a surface displacement hazard, even though offset most likely occurs at a much less rapid rate than that of tectonic faults. They are not regarded as having the capacity to generate damaging vibratory ground motion, can often be identified and avoided in siting, and their displacements can be monitored. Some growth faults and antithetic faults related to growth faults are not easily identified; therefore, investigations described above with respect to capable faults and fault zones should be applied in regions where growth faults are known to be present. Local human-induced growth faulting can be monitored and controlled or avoided.

If questionable features cannot be demonstrated to be of nontectonic origin, they should be treated as tectonic deformation.

D.17 R.E. Wallace, "Active Faults, Paleoseismology, and Earthquake Hazards: Earthquake Prediction—An International Review," Maurice Ewing Series 4, *American Geophysical Union*, pp. 209–216, 1981.

D.18 A.J. Crone and S.T. Harding, "Relationship of Late Quaternary Fault Scarps to Subjacent Faults, Eastern Great Basin, Utah," *Geology*, Volume 12, pp. 292–295, 1984.

D.19 O.W. Nuttli, "The Relation of Sustained Maximum Ground Acceleration and Velocity to Earthquake Intensity and Magnitude, State-of- the-Art for Assessing Earthquake Hazards in the Eastern United States," U.S. Army Corps of Engineers Misc. Paper 5–73–1, Report 16, 1979.

D.20 R.L. Street and F.T. Turcotte, "A Study of Northeastern North America Spectral Moments, Magnitudes and Intensities," *Bulletin of the Seismological Society of America*, Volume 67, pp. 599–614, 1977.

D.21 R.L. Street and A. Lacroix, "An Empirical Study of New England Seismicity," *Bulletin of the Seismological Society of America*, Volume 69, pp. 159–176, 1979.

D.22 USNRC, "Nuclear Power Plant Instrumentation for Earthquakes," Regulatory Guide 1.12, Revision 2.[1]

D.23 H. Rood et al., "Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant, Units 1 and 2," USNRC, NUREG–0675, Supplement No. 34, June 1991.[3]

D.24 S.M. Colman, K.L. Pierce, and P.W. Birkeland, "Suggested Terminology for Quaternary Dating Methods," *Quaternary Research*, Volume 288, pp. 314–319, 1987.

combined licensing procedure under 10 CFR Part 52 as an alternative to the two-step procedure of the past (Construction Permit and Operating License). In the past at numerous nuclear power plant sites, potentially significant faults were identified when excavations were made during the construction phase prior to the issuance of an operating license, and extensive additional investigations of those faults had to be carried out to properly characterize them.

E.2.2 Earthquake Recurrence Models

There are three elements of the source zone's recurrence models that could be affected by new site-specific data: (1) the rate of occurrence of earthquakes, (2) their maximum magnitude, and (3) the form of the recurrence model, for example, a change from truncated exponential to a characteristic earthquake model. Among the new site-specific information that is most likely to have a significant impact on the hazard is the discovery of paleoseismic evidence such as extensive soil liquefaction features, which would indicate with reasonable confidence that much larger estimates of the maximum earthquake than those predicted by the previous studies would ensue. The paleoseismic data could also be significant even if the maximum magnitudes of the previous studies are consistent with the paleo-earthquakes if there are sufficient data to develop return period estimates significantly shorter than those previously used in the probabilistic analysis. The paleoseismic data could also indicate that a characteristic earthquake model would be more applicable than a truncated exponential model.

In the future, expanded earthquake catalogs will become available that will differ from the catalogs used by the previous studies. Generally, these new catalogues have been shown to have only minor impacts on estimates of the parameters of the recurrence models. Cases that might be significant include the discovery of records that indicate earthquakes in a region that had no seismic activity in the previous catalogs, the occurrence of an earthquake larger than the largest historic earthquakes, re-evaluating the largest historic earthquake to a significantly larger magnitude, or the occurrence of one or more moderate to large earthquakes (magnitude 5.0 or greater) in the CEUS.

Geodetic measurements, particularly satellite-based networks, may provide data and interpretations of rates and styles of deformation in the CEUS that can have implications for earthquake recurrence. New hypotheses regarding present-day tectonics based on new data or reinterpretation of old data may be developed that were not considered or given high weight in the EPRI or LLNL PSHA. Any of these cases could have an impact on the estimated maximum earthquake if the result is larger than the values provided by LLNL and EPRI.

E.2.3 Ground Motion Attenuation Models

Alternative ground motion models may be used to determine the site-specific spectral shape as discussed in Regulatory Position 4 and Appendix F of this regulatory guide. If the ground motion models used are a major departure from the original models used in the hazard analysis and are likely to have impacts on the hazard results of many sites, a reevaluation of the reference probability may be needed using the procedure discussed in Appendix B. Otherwise, a periodic (e.g., every ten years) reexamination of PSHA and the associated data base is considered appropriate to incorporate new understanding regarding ground motion models.

E.3 PROCEDURE AND EVALUATION

The EPRI and LLNL studies provide a wide range of interpretations of the possible seismic sources for most regions of the CEUS, as well as a wide range of interpretations for all the key parameters of the seismic hazard model. The first step in comparing the new information with those interpretations is determining whether the new information is consistent with the following LLNL and EPRI parameters: (1) the range of seismogenic sources as interpreted by the seismicity experts or teams involved in the study, (2) the range of seismicity rates for the region around the site as interpreted by the seismicity experts or teams involved in the studies, and (3) the range of maximum magnitudes determined by the seismicity experts or teams. The new information is considered not significant and no further evaluation is needed if it is consistent with the assumptions used in the PSHA, no additional alternative seismic sources or seismic parameters are needed, or it supports maintaining or decreasing the site median seismic hazard.

An example is an additional nuclear unit sited near an existing nuclear power plant site that was recently investigated by state-of-the-art geosciences techniques and evaluated by current hazard methodologies. Detailed geological, seismological, and geophysical site-specific investigations would be required to update existing information regarding the new site, but it is very unlikely that significant new information would be found that would invalidate the previous PSHA.

On the other hand, after evaluating the results of the site-specific investigations, if there is still uncertainty about whether the new information will affect the estimated hazard, it will be necessary to evaluate the

REFERENCES

E.1 Memorandum from A. Murphy, NRC, to L. Shao, NRC, Subject: Summary of a Public Meeting on the Revision of Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100; Enclosure (Viewgraphs): NUMARC, "Development and Demonstration of Industry's Integrated Seismic Siting Decision Process," February 23, 1993.[1]

E.2 A.R. Ramelli, D.B. Slemmons, and S.J. Brocoum, "The Meers Fault: Tectonic Activity in Southwestern Oklahoma," NUREG/CR-4852, USNRC, March 1987.[2]

[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

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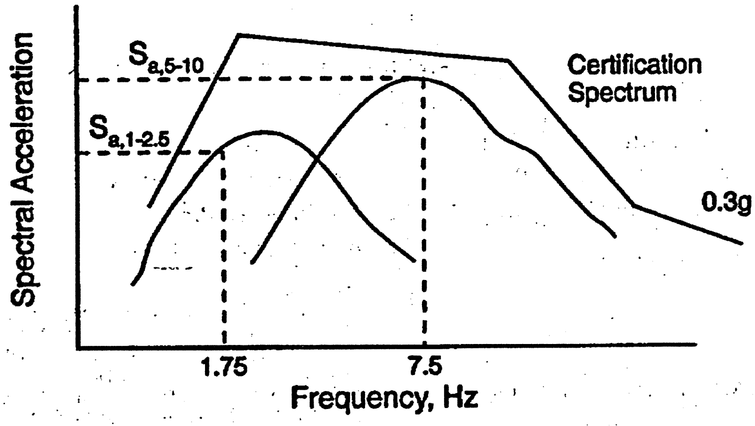

Figure F.1 Use of SSE Spectrum of a Certified Design

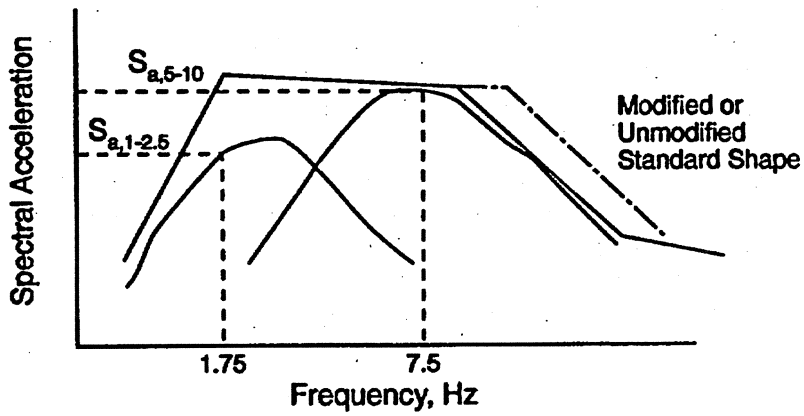

Figure F.2 Use of a Standard Shape for SSE

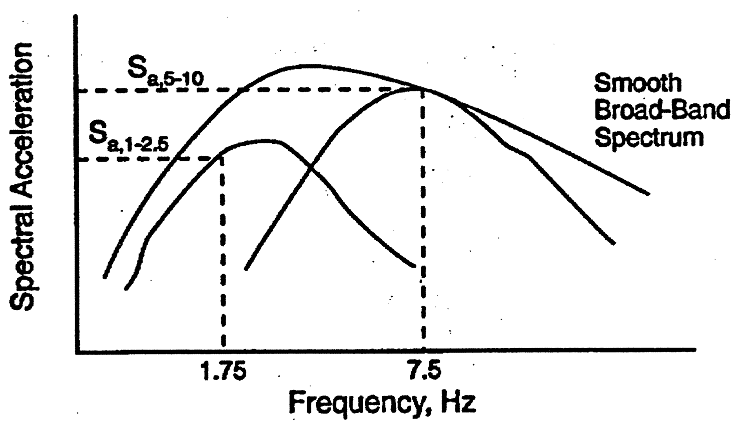

Figure F.3 Development of a Site-Specific SSE Spectrum

(Note: the above figures illustrate situations for a rock site. For other site conditions, the SSE spectra are compared at free-field after performing site amplification studies as discussed in Step 4 of Regulatory Position 4.)

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this regulatory guide. The regulatory analysis, "Revision of 10 CFR Part 100 and 10 CFR Part 50," was prepared for the amendments, and it provides the regulatory basis for this guide and examines the costs and benefits of the rule as implemented by the guide. A copy of the regulatory analysis is available for inspection and copying for a fee at the NRC Public Document Room, 2120 L Street NW. (Lower Level), Washington, DC, as Attachment 7 to SECY-96-118.